

2 Entrance Engineering¹

This chapter describes the existing navigation project and reviews maintenance dredging that was conducted in the past. Vessels transiting the navigation channel at Willapa Bay are discussed, and a project design vessel for this study is defined. The limits of environmental operating conditions for vessels are reviewed. An examination of channel stability is made, and significant tidal inlet parameters are presented to aid in considering a safe and reliable Willapa Bar navigation channel. Placement or disposal sites of dredged material are also discussed, together with estimates of the associated costs. Further information on disposal sites is given in Appendix H.

Project

This section summarizes the navigation project at the entrance to Willapa Bay. Depths are referenced to mean lower low water (mllw). Figure 2-1 shows the project layout. The seaward channel over the bar does not appear in this figure because it varies in position in time and is marked by the U.S. Coast Guard (USCG) based on U.S. Army Engineer District, Seattle, surveys. The existing project, adopted 27 July 1916, and last modified 3 September 1954 (U.S. Congress 1916, 1954), provides the following:

- a. A channel over the bar at the mouth of Willapa Bay, 26 ft deep and at least 500 ft wide. Overdepth of 2 ft is allowable.
- b. A channel 24 ft deep and 200 ft wide from deep water in Willapa Bay to the foot of Ferry Street in South Bend, then 300 ft wide to the westerly end of the narrows, then 250 ft wide to the forks of the river at Raymond, including a cutoff channel 3,100 ft long at the Narrows.
- c. A channel 24 ft deep and 150 ft wide up the South Fork to the deep basin above Cram Lumber Mill, and up to the North Fork to 12th Street, with a turning basin 250 ft wide, 350 ft long, and 24 ft deep.
- d. A channel 10 ft deep and 60 ft wide from deep water in Palix River to Bay Center Dock.

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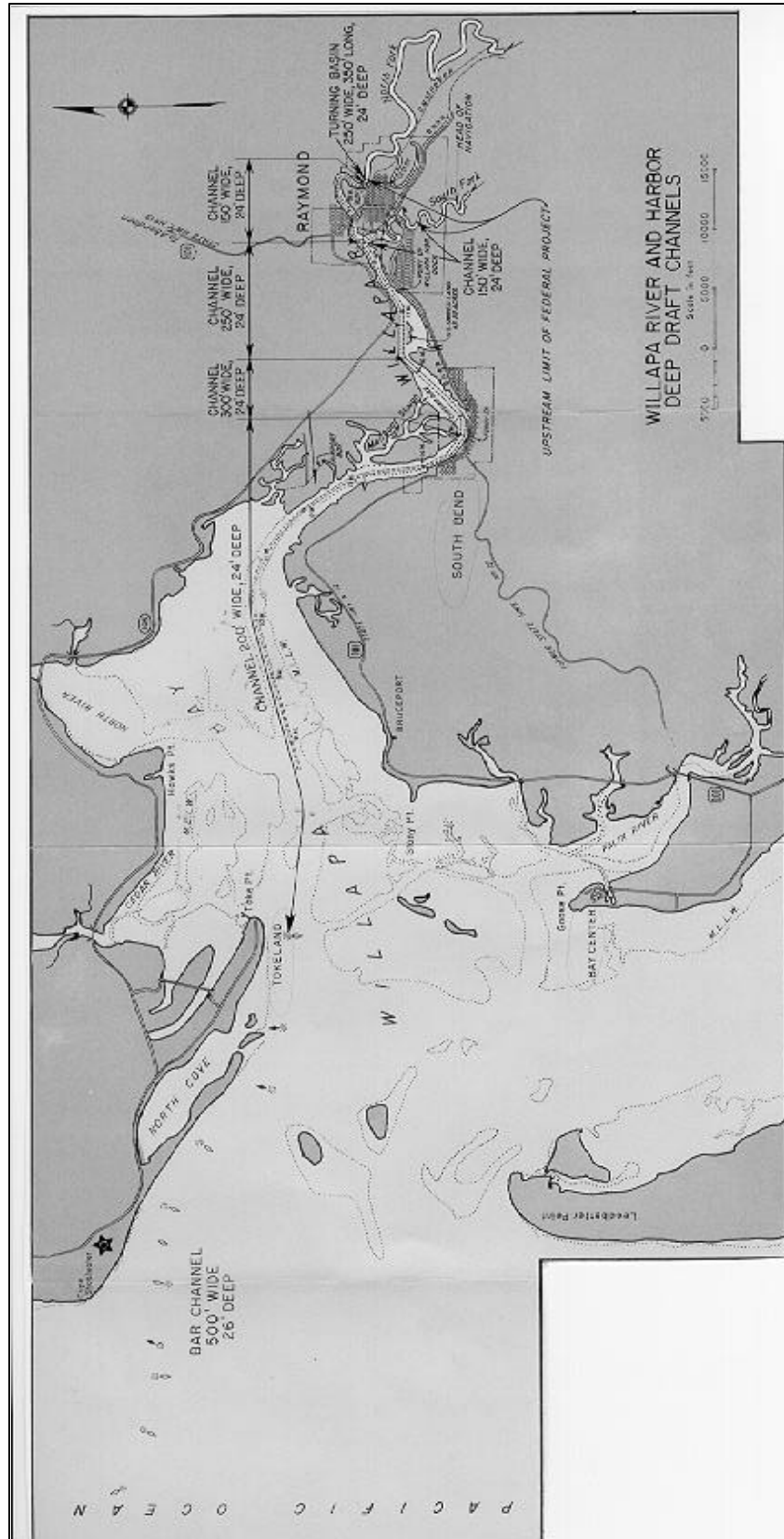


Figure 2-1. Willapa River and Harbor navigation channels (project map, Seattle District)

- e. An entrance channel 15 ft deep and 100 ft wide and a mooring basin 15 ft deep, 340 ft wide, and 540 ft long adjacent to port wharf at Tokeland.
- f. An entrance channel at Nahcotta 10 ft deep and 200 ft wide and a mooring basin 10 ft deep, 500 ft wide and 1,150 ft long, protected by a rubble-mound breakwater approximately 1,600 ft long.

The entrance channel and Willapa River channels were completed in 1936, with additional widening completed by 1958. Annual maintenance costs for 1964-1970 averaged \$468,400, but did not provide full project depth year-round. At the 1998 time of study initiation, the controlling depth over the curved north channel ebb shoal was about 20 ft, and the controlling depth in the river channel reach was about 17 ft. (Note: By October 1999, the controlling depth over a straight-out north channel improved to about 24 ft.) As can be noted from the authorized widths and depths of the river channel reach, a variation existed in the size of vessels capable of traversing certain parts of the project.

Recent dredging amounts taken from the bar channel are shown in Table 2-1. Over a 23-year period, the annual volume removed averaged 288,000 cu yd, with a maximum of 610,000 cu yd dredged in 1969, an indication of the cyclic movement of large masses of sediment. One should also note that typically the authorized depths were maintained for only a few months before depths again became less than 26 ft, indicating substantial sediment infiltration along the channels. Dredged volumes were determined in part by the schedule of availability of Government hopper dredge equipment. A complete chronology of Willapa Harbor dredging is presented in Table H-1 of Appendix H.

Table 2-1 Willapa Harbor-Bar Channel O&M Hopper Dredging			
Year	Volume 1,000 cu yd	Year	Volume 1,000 cu yd
1951	308	1965	955
1953	30	1966	303
1956	187	1967	341
1957	256	1968	459
1958	253	1969	610
1959	237	1970	324
1960	222	1971	340
1961	282	1972	274
1962	453	1973	189
1963	282	1974	42
1964	278	1997 Test Dredging	80
Note: dredged volumes reflect schedule of availability of government hopper dredge, i.e., dredging may not have returned the channel to design dimensions.			

Vessels

Historic log and lumber ships planning to enter Willapa Harbor typically would have fully-loaded drafts of 28 to 33 ft. Because of the inadequate channel depths and shifting outer bar channel, the Twin Harbor Pilots Association has

restricted loadings to 20-ft drafts, or one-third capacity, which require the vessel to top off at another port. Also, the pilots have restricted sailings to daylight hours. A table in the Feasibility Report (U.S. Army Engineer District, Seattle, 1971) for years 1964-70 indicated that 1964 had the highest number of log exports and lumber shipments, with 88 shipments. The number decreased yearly to 45 shipments in 1970. This industry has migrated to Grays Harbor, so it is questionable if the entrance should be designed for this size vessel. In addition, the newer lumber ships have 37-ft drafts, which would require a deeper authorized channel. Most likely though, if Willapa Bay is to be made a viable port again, some type of cargo vessel should be considered in the design process.

Commercial fishing vessels, charter boats, towboats, and recreational and other small craft presently would have little difficulty with the previously maintained bar channel depths (U.S. Army Engineer District, Seattle, 1971). Drafts of these vessels are on the order of 12 to 16 ft. Potential harbor tenants originate from the tuna boat fleet, and these vessels have 17-ft drafts. Channel shifting, strong currents, and turbulence created by storm waves breaking over shoals make passage hazardous for this size vessel. No criterion was found to determine the level at which the wave breaking turbulence becomes critical to this size vessel.

Tugs (draft, 13 ft) and their barges (draft, 11-12 ft, 236-ft-long by 60-ft-wide) require straight channels for accommodating the length of the towline. Grounding incidents point to channel curvature as a main cause of navigation difficulty. The tugs require waves less than 9 ft for safe navigation. Barges experience 15 to 20 ft of vertical motion around still-water level in the presence of such waves, based on 30-deg roll with 60-ft beam and 10-deg pitch with a 236-ft length.¹ The vertical motion contributes to produce an effective draft of 27 to 32 ft mllw. If vessels enter and exit at the +6-ft tide level, a channel depth of 21 to 26 ft is required. Pitching dominates at the outer bar and, at the inner bar, rolling is likely to dominate from reforming waves.

Design Vessel

The design vessel is “usually ...the largest vessel of the major commodity movers” (Headquarters, U.S. Army Corps of Engineers 1996). Another approach, taken in the Grays Harbor project, is to select a vessel that carries the majority of product tonnage, then check for adequacy of movement of the largest vessels. The design ship draft for Grays Harbor was 37 ft (for a 46-ft-deep by 1,000-ft-wide authorized project). Presently, the decision for Willapa Bay would have to be based on tug and barge traffic to satisfy the criterion of the largest vessel of the major commodity mover. (This decision follows because the deeper draft lumber ships are not calling at Willapa Bay. However, tugs and barges are also not calling there at present, but they are the most recent commodity hauler other than commercial fishing vessels.) For the given project authorization of 26 ft, the tug-barge combination or a commercial fishing vessel apparently should be the design vessel. To design for the draft of the most recent lumber ships would require a significant increase in authorized depth.

¹ Letter to U.S. Army Engineer District, Seattle, from Brix Maritime Company, 12 May 1992.

Design Criteria

Criteria for determining entrance channel depth, width, and alignment (with respect to wave approach) depend upon the specific vessel. Figure 2-2 shows the factors involved in determining channel depth. Taking Figure 2-2 as a guide and assuming a 13-ft draft for a tug, combined squat and trim is less than 2 ft for this vessel traveling at 10 knots in a wide fairway such as the ocean bar region (Headquarters, U.S Army Corps of Engineers, in preparation). Advance maintenance dredging and dredging tolerance (neither is included as part of the design (authorized) depth) will be assumed combined as 2 ft. Safety clearance is normally taken as 2 ft.

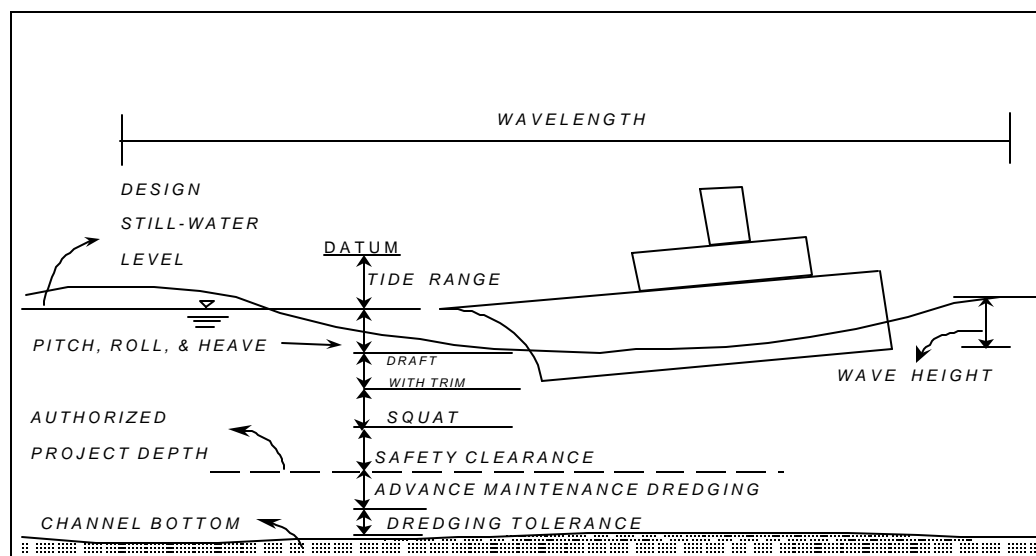


Figure 2-2. Channel depth allowances and wave steepness defined as wave height divided by wavelength

At a high-wave location such as Willapa Bay, a large part of the channel design depth is associated with the vessel movement because of vertical components of pitch, roll, and heave resulting from wave motion. Wave-accompanying effects tend to increase as wave height increases and decrease with greater ship length. A typical ship motion response amplitude operator (RAO) is 1.2. The RAO is a dimensionless factor with which to multiply wave amplitude (amplitude being one-half the wave height) for determining the distance below the still-water level to which the ship will move in waves of given height.

Values of RAO measured in the mouth of the Columbia River ranged from 0.9 to 2.2 for bulk carriers, 1.0 to 2.1 for tankers, and from 0.4 to 1.2 for container ships (Headquarters, U.S. Army Corps of Engineers, in preparation). If an operational wave height of relatively high energy is taken as 9 ft, then the additional channel depth required would be $1.2 \times 4.5 \text{ ft} = 5.4 \text{ ft}$.

Combining wave amplification response and draft, squat, and safety clearance determined previously yields a value of 22.4 ft. This depth contains tolerance and leaves room for navigating in higher wave conditions, up to 15-ft

wave heights in the channel. The value for a fishing vessel with a 17-ft draft would be 26.6 ft for the 9-ft wave condition, probably an acceptable value because of inclusion of a safety clearance. In other words, wave conditions of 9 ft or less in the channel would be necessary for relatively safe operations for the design vessels.

Required channel width can be determined by evaluating factors as outlined in Permanent International Association of Navigational Congresses (1997). The basic maneuvering lane for a vessel of low maneuverability (such as a tug/barge system) is $1.8B$, with B the beam of the design vessel. For strong crosswinds of a slow-moving vessel, a factor of $1.0B$ is added. If strong crosscurrents are present, $1.3B$ is added. For strong channel currents and slow vessel speed, $0.4B$ is added. For significant wave heights greater than 10 ft, $1.5B$ is added. If visibility is frequently poor, one should add $0.5B$. For shallow, hard bottoms, one should add $0.3B$. The total is $6.8B$. For a 60-ft beam, a width of 408 ft would be required. The 500-ft authorized width meets that requirement. A possible reason and benefit for increasing channel width is to add storage capacity for sediment moving into the side of the channel from spits and shoals. The storage capacity would extend the time interval between dredging operations required to maintain the authorized channel depth and width, but would require a dredge to remain on site longer during maintenance.

At times an S-curve is present as a spit emerging from the north beach pushes the North Channel to the south before it can again turn to the west and exit to deeper water. Chapter 3 discusses this channel pattern in its historical context. In this study, 1,500 ft of channel width was estimated to be required for tows entering an S-curve, allowing for as much as a 45-deg angle off the center line of the tug. Towlines are typically 300 to 500 ft long, with a minimum of 100 ft. Tugs are typically in the 65- to 100-ft-length range, and barges are 150 to 400 ft long. The 1,500-ft width is based on the maximum dimensions of the towline, tug, and barge.

The orientation of channel alignment with respect to wave approach (and thus vessel alignment to some degree; however, the vessel may change its orientation with respect to waves if the channel is wide enough) enters into consideration of navigability. In examination of wave conditions for various alternatives, a value of ± 45 deg was selected based on limited output of a ship motion model called HYDRO.¹ Figure 2-3 shows the effect of wave angle on a bulk carrier in terms of wave period versus the RAO. The three wave angles examined were 0 deg (the vessel is moving directly into the wave crest), 45 deg to the vessel center line, and 90 deg, with the wave hitting the vessel broadside. Important to note is that the 0- and 45-deg curves are in about the same range RAO over the various wave periods. For the 90-deg wave, the RAO peaks up to a much higher value, as the vessel is near resonance with the 12-sec wave in the roll mode. Based on this example, the "45-deg window was selected for evaluating alternatives.

¹ Personal Communication, 1998, Mr. Frank Sargent, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

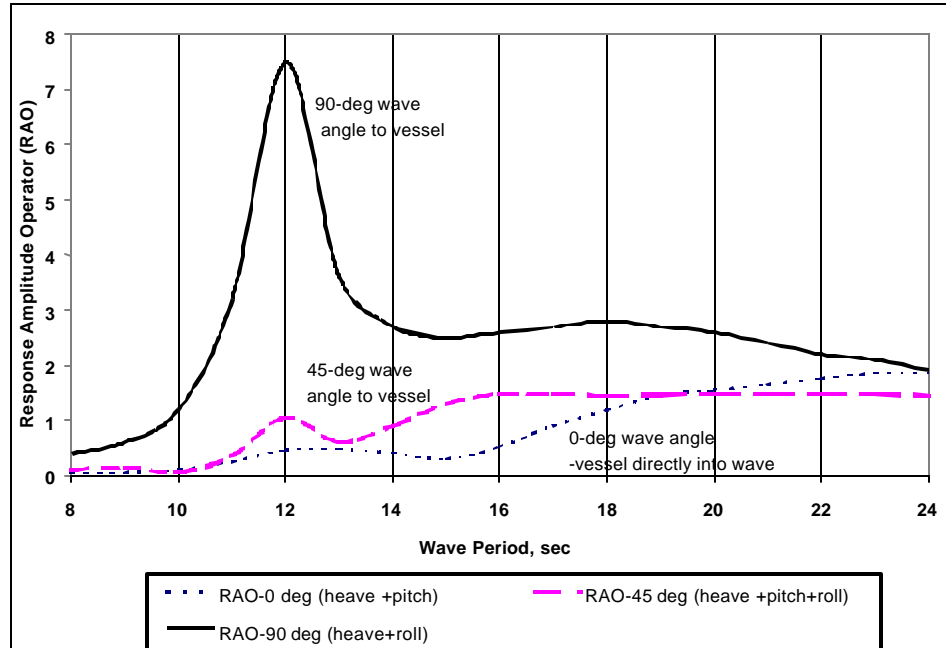


Figure 2-3. Response amplitude operator versus wave period for 0-, 45-, and 90-deg wave angles approaching an 824-ft-long, 106-ft-beam, 42-ft-draft bulk carrier

Kraus (1997) proposed a wave steepness criterion for establishing navigation safety in a channel. Wave steepness is defined as the wave height divided by the wavelength. A critical value of 0.05 was recommended as preliminary guidance, above which there was concern for the safety of vessels with lengths on the order of that of the incident waves. The incident wave steepness increases if waves meet an opposing (ebb) current. The steepening of individual waves in a wave train creates a “washboard” or chop that can be difficult to navigate.

Grays Harbor Experience

Grays Harbor, Washington, lies to the north of the Willapa entrance and is a Federal navigation project. Information from the Grays Harbor General Design Memorandum (U.S. Army Engineer District, Seattle 1989) indicates that recent log vessels are 25,000 to 30,000 dwt, with 570-ft lengths, 87-ft beam, and design drafts of 34 to 37 ft, departing at higher tide levels. At Grays Harbor, the outer bar channel is aligned along a southwest azimuth based on pilot preference. Grays Harbor pilots indicate they are concerned about being set by currents, and by the wind and vessel pitch, rather than by roll of the vessel. The channel dimensions for the Grays Harbor project are 30-ft depth by 600-ft width over the bar and through the entrance.

Operationally, transits from docks begin 3 hr or more after low tide to move against the flood current for better steerage, to obtain additional keel clearance, and to avoid hazardous ebb-flow conditions. The 30- to 37-ft draft vessels transit the entrance channel only in optimum conditions. Depth allowances for vessel pitch, roll, and heave in waves moving over the ebb bar are 14 ft. Channel width

for strong currents and waves is 600 ft in the entrance and 1,000 ft at the seaward end of the entrance channel and across the bar.

The maximum significant wave height allowable for outbound transits is about 8 ft for flood tide conditions. Studies by Wang et al. (1980) showed maximum excursion of the bow will be less than 14 ft for 95 percent of the time under these conditions. Maintenance dredging at Grays Harbor occurs mostly in the interior. The twin jetties at Grays Harbor function to maintain depths in the entrance channel and over the ebb shoal so that no significant maintenance dredging is required for a 30-ft-depth channel (U.S. Army Engineer District, Seattle, 1989). The presently-maintained project (46-ft-deep channel 1,000 ft wide at the entrance bar) is estimated to require dredging of 100,000 to 200,000 cu yd/year in the entrance channel and less than 100,000 cu yd/year at the entrance bar.

Existing Navigation Conditions and Navigation Safety¹

Vessels avoid exiting Willapa Bay on the ebb because of longer transit time when waves are present. When a vessel exits on the ebb, with some waves breaking in the channel, reading the waves and estimating which ones will break is a difficult procedure for the navigator. The navigator needs to slow down as the ebb current pushes the vessel ahead while he or she evaluates if a wave will break. The vessel is attempting to avoid the chaotic wave action of the breaking wave that would then wash over it. For example, every 5 min, two or three waves may break. This lower exit speed increases time of exposure in the entrance channel. In the case of tug-barges, the decrease in speed reduces the control of the barge, permitting crosscurrents and wind to push the barges out of line with the tug.

In the region from Cape Shoalwater into the bay, strong chop exists that can be difficult to navigate and, in the case of tows, again makes the barge wander behind the tug. Also, while in this region, no deck work can be performed, but the vessel is not in danger similar to that when on the bar channel.

When a vessel is traveling in the S-curve of the North Channel, extreme breaking conditions may exist for waves from the northwest and the west and wave angle with respect to the vessel travel may be large. The washboard conditions are difficult for navigation. Within the seaward east-west part of the S-curve, 400 ft of migration of the channel thalweg can occur within one month. Conditions are usually acceptable if swell height is less than 3 ft and the vessel travels in late ebb, flood, and early ebb. Vessels will avoid moderate and greater ebb-flow conditions when moderate to large waves are present. No knowledgeable local boat captain wants to navigate the bar channel at night with ebb conditions. Navigation at slack or early flood is acceptable if there is not much swell; otherwise, boat captains will wait for stronger flood flows before exiting during conditions with larger waves.

¹ Information in this section was obtained during a 30 October 1998 telephone conversation with Mr. Randy Lewis, formerly Warrant Officer USCG (retired) stationed at Willapa Bay.

Willapa Bay Design Conditions

Based on available information, two design vessels were selected: a tuna fishing vessel with a draft of 17 ft and a tug/barge vessel combination (13-ft draft tug and barge with a 12-ft draft, 236 ft long by 60 ft wide). The best alternative should be selected in part considering the highest percentage of time with waves less than 9 ft in height on a flood tide. Wave angle with respect to channel alignment should be less than 45 deg to avoid significant roll of the vessel. Head-on waves do not always present the best wave angle for tug-barge combinations because this can produce extra tension in the towlines if the tug-barge systems are in phase with one another. Channel depth must be greater than 26 ft at all times. The barge-tug vessel will require a relatively straight channel alignment and a minimum width of 1,500 ft if an S-curve exists.

Inlet Channel Stability

Willapa Bay has existed as a relatively stable inlet for more than a century by maintaining a strong tidal exchange of water entering and exiting the inlet. A Coast and Geodetic Survey nautical chart, Number 6185, for the period of 1887-1897, indicated that the mean tide range was 7.4 ft at Sealand (Nahcotta) and 7.5 ft at South Bend (with a mean ocean tide range of 6.2 ft). Present National Ocean and Atmospheric Administration Tide Tables indicate that the mean range is 7.9 ft at Nahcotta and 7.8 ft at South Bend. These numbers may not be directly comparable because of improvements in measurement technology, but in each case, one can note the recent bay range was only slightly greater than the earlier tide range. Consequently, the overall tidal hydraulic condition of the inlet system has been relatively constant over the past one hundred years.

If the slight increase in bay tidal range has actually occurred, this would follow from a trend seen in the measurement of minimum cross-sectional areas of the inlet entrance. The minimum area (determined by measurement of the inlet cross section at the minimum width, considered to be a reasonable assumption) increased from 450,000 sq ft in 1877, to 480,000 sq ft in 1937, to 520,000 sq ft in 1967, to 530,000 sq ft in 1996. There is some amount of uncertainty in these area calculations because of lack of data in very shallow regions together with the usual possibility of measurement error related to many other factors. Errors in tidal datums could lead to large errors because of the large width of the inlet. For example, a variation of ± 0.5 ft over the approximate 20,000-ft width leads to a cross-sectional variation of $\pm 10,000$ sq ft. Therefore, a variation of 20,000 sq ft should be assigned.

The minimum cross-sectional area is considered as a measure of the tidal prism (defined as the volume of water entering (or leaving) the bay during a flood (or ebb) portion of the tidal cycle). The minimum cross-sectional area A_c (measured at mean tide level) is related to the spring or diurnal tidal prism P as

$$P = 5 \times 10^4 A_c \quad (2-1)$$

This equation is from O'Brien (1931) based primarily on data from Pacific Ocean inlets of the United States. Jarrett (1976) determined similar relationships for

east coast, west coast, and Gulf coast inlets. Using Equation 2-1 and the 1996 area, an estimate for P would be 2.65×10^{10} cu ft, a value near the maximum for United States inlets. Escoffier (1940, 1977) developed an analytical or graphical method to examine the stability of coastal inlets. This technique (Seabergh and Kraus 1997) is applied to Willapa Bay in Figure 2-4.

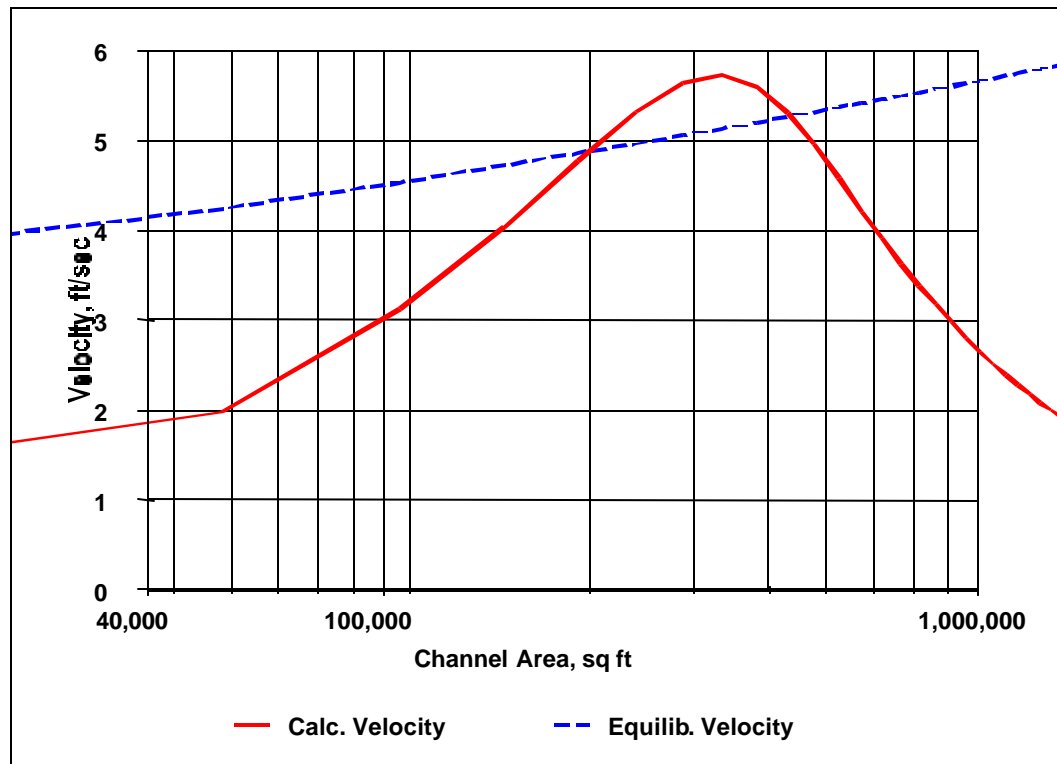


Figure 2-4. Escoffier diagram for Willapa Bay. Plot shows average maximum velocity versus minimum inlet area (solid line) and the equilibrium velocity curve (dashed line). Intersection of curves on right side indicates stable equilibrium area for Willapa Bay, 447,000 sq ft, based on assumptions discussed in text

The intersection of the curves on the right side in Figure 2-4 is a stable equilibrium area (447,000 sq ft). The inlet area would vary about this value through sediment flux into and out of the channels and changing tidal conditions (e.g., spring to neap tide range variation). The left-hand intersection is an unstable equilibrium area (200,000 sq ft). If the minimum area became smaller than this minimum value because of a large influx of sand, the inlet would close. The historical values are on the high side of stable equilibrium. These higher values of inlet area are in qualitative agreement with the long-term scouring of the north shore. This analysis shows that overall the inlet is stable at the minimum cross-sectional area location and, by flow continuity, the larger offshore cross sections maintain relatively constant flow areas even as the distribution of flow and number of channels change (Chapter 3). However, channel migration caused by movement of sand in the more seaward region creates local instability of channel location and hazards to navigation because of

movement and curvature. These patterns of shoaling and channel movement are governed by the influx of sediment discussed in Chapter 3.

The result of a reduction in channel flow area can be determined by consulting Figure 2-4. For example, building the State Route (SR)105 Emergency Project on the north shore reduced the flow area in the channel 30,000 sq ft. Assuming the reduction is near the location of the minimum cross-section area, the flow area (530,000 – 30,000 sq ft) would still be above the stable equilibrium area (447,000 sq ft). Even if the inlet were at its stable area of 447,000 sq ft, a reduction of 30,000 sq ft in inlet area to 417,000 sq ft would still be in the range where the inlet area would be returned to its stable equilibrium area by cutting a deeper or wider channel. Bathymetric data from recent surveys support this conclusion.

An increase in flow area, as produced by excavation of a larger channel, would move along the solid curve to the right showing an increase in area, but a reduction in velocity. The result would be an infilling of the channel and a return to the equilibrium area. This evaluation describes the system as a whole and does not link changes in one region to changes in another; e.g., if the South Channel would shoal, one would expect an increase in area in the Middle or North Channel to maintain the equilibrium of the whole system, but this analysis cannot predict which channel would deepen.

Development of Design Alternatives

The development of alternatives is based on selection of channel alignments and channel size that meet certain criteria. First, a reliable channel is desired. A reliable channel is one that can be maintained to provide safe navigation based on present and design vessel usage. It must also meet a certain benefit cost ratio and be environmentally acceptable (not discussed in this report). Therefore, the three engineering points to consider in evaluating alternatives are as follows:

- a. Estimated project scope (initial dredged volume).
- b. Estimated average annual maintenance volume.
- c. Navigation safety.

Based on examination of historical maps of the inlet as discussed in Chapter 3, three main locations of potential egress to the ocean from Willapa Bay exist, not all of which are usually present at the same time (Figure 3-1). A North Channel is identifiable on all maps of the inlet; however, because of spit growth from the north, sometimes the North Channel has exited into the ocean through a wide range of angles, from toward the northwest to the southwest. The present Middle Channel typically does not connect directly to the ocean bar, but is incised centrally in the middle of the inlet. Its present geographic location was once the main exit to the sea, probably because of its alignment with the Willapa River. During the past 100 years with the movement of the channel northward and erosion of Cape Shoalwater, the Middle Channel has not been the dominant flow channel. The South Channel is ephemeral, and it is incised in the shallow shoal similar to the Middle Channel. The analysis in Chapter 3 characterizes the longevity, location, depths, and orientation of the channels in a historical perspective.

Possible alternatives are summarized in Table 2-2, and the initial dredging volumes required (based on 1998 bathymetry) are presented in Table 2-3. During the 18-month period of Phase I studies, the volume of sediments associated with the bar channel improvement from a 20-ft deep curved (Alternative 3B) alignment to a 24-ft deep (approximating Alternative 3A) alignment exceeds 20 million cu yd without dredging. Volumes vary between 0.2 and 9.9 million cu yd for the depths and widths described in Table 2-2. The list of 19 alternatives was developed without preconception of a preferred alternative, and moderate to extreme (expensive) alternatives were considered. The alternatives were screened in the course of the study, with some initially deleted based on reasoning described in the next paragraphs, and some alternatives deleted after reconnaissance numerical simulations as described in Chapter 6, to arrive at a subset for detailed examination. An additional aspect in evaluation of alternatives is potential beneficial uses of dredged material, such as for protection of the North Beach shore and creation of bird islands, oyster habitat, and wetlands (Appendix H). Further refinement of the described alternatives and possible addition of new alternatives are expected during the future course of this study.

Table 2-2 shows that the existing procedure (numbered as Alternative 1) is considered an alternative as it is the least costly approach, and it also defines the existing condition against which other alternatives may be compared. Alternative 2 is considered in terms of a future existing condition where opportunistic dredging may provide a reliable channel. This alternative is defined by future conditions and thus is not examined in the modeling. All Alternative 3 variations focus on using the North Channel. Alternative 3A proposes a straight channel at its present northernmost location (Figure 2-5). Alternatives 3B and 3C are based on improving the width of the S-curve, which evolves if the spit from the north is permitted to grow southward. Initially, two cases of S-curve channels were proposed for investigation.

The 3B Alternative (Figure 2-5) is based on the present (1998-1999) bathymetry, and the 3C Alternative is based on historical analysis (Chapter 3) where the channel, extending southward, parallels the ocean bar for up to 2.5 miles. Dredging could be minimized for this configuration, as the channel markers could be moved to follow the southward migration. The major drawbacks would be exposure of vessels to turbulent broken waves broadside and requirement by the USCG for the Seattle District to survey the channel prior to relocation of navigation aids. Based on the dangerous wave condition of 3C, only 3B was selected for study. Alternative 3D raised the new SR-105 dike to -2.0 mllw elevation. Alternative 3E consisted of construction of a jetty on the north side of the entrance (Figure 2-5), primarily as a terminal groin or holding structure for sediment, which might enable trapped sediment to move back up the coast with winter storm waves. Alternatives 3F and 3G are similar in orientation to 3A and 3B, with the difference in increased channel width and depth providing increased sediment storage, thus increasing the time between project maintenance operations.

Table 2-2
Definition of Design Alternatives, Willapa Bay Navigation Channel Reliability Study¹

Alternative	Description	Potential Benefits and Beneficial Uses	Estimated Feasibility
1. Existing Procedure	USCG directed to move channel markers according to natural shift in channel detected in Corps surveys. An S-curved channel could remain.	Least costly O&M alternative	Low – cannot maintain a navigable channel. Would require frequent surveys
2. Modified Existing Procedure	Same as 1, but with dredging performed opportunistically anywhere according to need and to improve (widen) any curved channel condition	May be least costly because of probable low frequency of dredging	Fewer and random beneficial uses. Requires frequent surveys and subject to availability of funds and dredging equipment suited to Willapa Bar
3. Maintain North Channel	Maintain north channel at reasonable cost	Opportunity to place dredged material on North Beach	
3A	Dredge primarily on entrance bar, straight out and fixed in position	Safe navigation route. Possible opportunity for beach nourishment	Most feasible relative to navigation alignment
3B	Modified S-curve (moderate curve)	Possible opportunity for beach nourishment	Feasible if 1,500-ft width available
3C	Modified S-curve (extreme allowable curve)	Possible opportunity for beach nourishment	Not desirable due to difficult navigation
3D	Raise the SR-105 dike (-2 ft mllw) and dredge on entrance.	May reduce erosion on North Beach	Expensive first cost
3E	Construct jetty from tip of Cape Shoalwater and dredge as required	Reduce persistent infilling of channel from the north	Expensive first cost
3F	Same as 3A, except dredge to total depth of 38 ft mllw and with width 1,000 ft	Reduced frequency of maintenance and potential shoaling from the north. Easier navigation	Subject to availability of high-production dredge equipment
3G	Same as 3B, except dredge to total depth of 38 ft mllw and with width 1,000 ft	Reduced frequency of maintenance and potential shoaling from the north. Easier navigation	Relatively expensive due to initial dredging cost
3H-a	Existing SR-105 dike and deepening on potential new channel south of North Channel	If new channel continues to break through, would be beneficial for north shoreline	If new channel breaks through, will be the present channel
3H-b	SR-105 dike raised to -2 ft mllw (3H-b) and deepening on potential new channel south of North Channel	More sheltering for North Cove shoreline; some deflection of flow away from North Channel	Expensive first cost. If new channel breaks through, will be the present channel.
4. Maintain Middle Channel	Maintain Middle Channel at reasonable cost	Shortest route from Bay Center	Enhanced flow to help maintain Bay Center channel
4A	Dredge primarily on entrance bar	Shortest route	If dredged entrance bar, beneficial uses doubtful

(Continued)

¹ All channel depths are 26 ft mllw + 2 ft overdredging (500-ft width at bottom) unless otherwise specified.

Table 2-2 (Concluded)			
Alternative	Description	Benefits and Beneficial Uses	Feasibility
4B	Construct training structure northwest of Bay Center to direct flow away from the North Channel and into the Middle Channel. Dredge on entrance bar only	Create bird islands, oyster grounds; would reduce current along the North Beach	Need to investigate possible changes to navigation at Bay Center and Toke Point; expensive
4C	Construct training structure northwest of Bay Center to direct flow away from the North Channel and into the Middle Channel; dredge primarily on bay (funnel the ebb flow) and dredge on entrance bar.	Create strong Middle Channel; reduce flow in North Channel and erosion on North Beach	Expensive
4D	Construct training structure north of Willapa River entrance to direct flow from North Channel and into Middle Channel. Dredge on entrance bar only	Create strong middle channel; cut off flow in north channel and reduce erosion on North Beach	Need to investigate possible changes to navigation at Bay Center and Toke Point; expensive
4E	Same as 4A, except dredge to total depth of 38 ft mllw and with width 1,000 ft	Reduced frequency of maintenance. Easier navigation	Need to investigate possible impacts on navigation at Bay Center and Toke Point; expensive first cost
5. Maintain South Channel	Maintain South Channel at reasonable cost	--	Doubtful because of lack of data on channel longevity and longer transit for most users
5A	Dredge primarily on entrance bar	Potentially shorter length of dredging to deeper water. Similarity to Grays Harbor	Doubtful because of lack of data on channel longevity and longer transit for most users
5B	Dredge primarily on bay (funnel the ebb flow)	Same as 5A	Considered infeasible because curvature would be too great to capture flow out of the South Bay on ebb
6. Follow Natural Channel	Implement either 3A or 4A according to opportunity	May result in least dredging and safest navigation if careful surveying is done	May be difficult to know when the deepest channel has switched location with stability

Table 2-3 Initial Dredging Volumes Assuming a Static 1998 Bathymetry		
Alternative	Short Description	Volume (1,000,000 cu yd)
3A	Straight North Channel	0.8
3B	Curved North Channel, 500- to 2,500-ft width	0.2
3C	Extreme curved North Channel	Somewhat greater than 0.2
3D	Raise SR-105 dike with straight North Channel	0.8
3E	North Channel with jetty	0.8
3F	3A orientation, 38- x 1,000-ft channel dimensions	5.0
3G	3B orientation, 38- x 1,000 ft channel dimensions	4.2
3H	Arm off south side of North Channel at dike	2.1
4A	Middle Channel (bar dredging)	3.0
4B	Bay Center training structure with 4A	2.6
4C	Dredging across whole entrance with 4B	9.9
4D	Willapa River training structure with 4A	2.6
4E	4A orientation with 38- x 1,000-ft channel dimensions	12.0
Note: Unless noted otherwise, channels are 500 ft wide at the bottom and have 1V:3H.		

Alternatives 3H-a and 3H-b were selected for evaluation after new bathymetric measurements made during the course of the study indicated some deepening of the southside of the North Channel just seaward of the SR-105 project. The two alternatives were added to determine if any advantages could be found in placing a navigation channel in this vicinity. Alternative 3H-b included raising the elevation of the SR-105 dike from -18 ft mllw to -2 ft mllw, to deflect additional flow through the potential channel location.

Alternative 4 variations were all located at the Middle Channel region (Figure 2-5). The Middle Channel would provide the shortest route for vessel traffic. The alternatives were developed based on evidence that major ebb flow exits the North Channel. Therefore, Alternative 4 variations were designed in an effort to divert flow through the Middle Channel to enhance its persistence at that location. Alternative 4A involved dredging on the bar, which would provide a baseline for the more diversionary alternatives. Alternative 4B provided a training structure just northwest of Bay Center. Alternative 4C added a channel extending seaward from the training structure of 4B to determine if additional dredging might enhance capture of the diverted ebb flow. Alternative 4D consisted of a training dike north of the Willapa River entrance to guide flow directly into the existing bay entrance of the Middle Channel. Alternative 4E was similar to 4A except for the additional sediment storage provided by a deeper and wider channel as was done for Alternatives 3F and 3G.

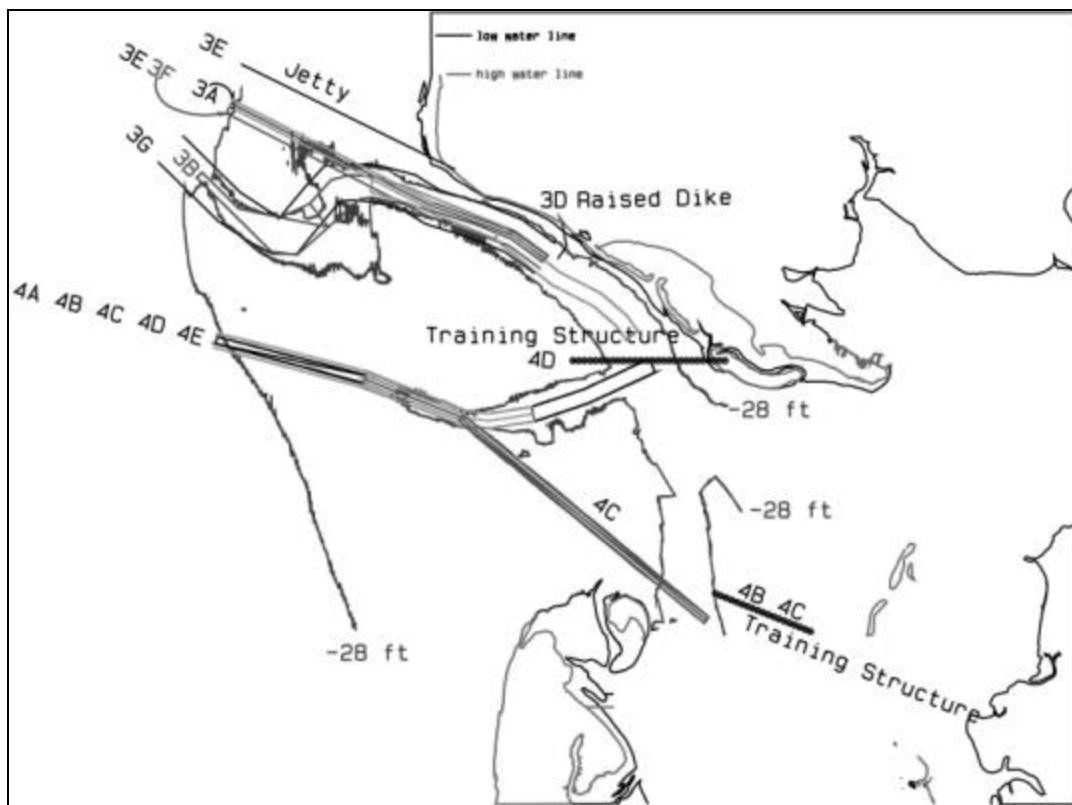


Figure 2-5. Channel and structure location for alternatives

Alternative 5 variations were located at the South Channel. Alternative 5A proposed dredging on the bar side and 5B included bayside dredging. These alternatives were not investigated further because their curvature was considered too great to capture ebb flow out of South Bay and because of the high influx of sediment likely to occur over the entire channel length with winter storm waves.

Alternative 6 would consider implementing Alternative 3A or 4A according to which one would require least dredging. This was not an option to be model studied.

In summary, Alternatives 1, 3A, 3B, 3D, 3E, 3F, 3G, 4A, 4B, 4C, 4D, and 4E were designated for the calculation-intensive tidal hydrodynamics and sediment-transport simulations. A subset of these that showed potential was then examined in the short-wave model. Chapters 5 and 6 describe the short-wave and long-wave simulations, respectively.

Initial Dredging Requirements

A major consideration in the evaluation of channel alternatives by cost is the considerable difference that exists in initial dredging requirements. These differences are examined quantitatively by mathematically cutting design channels into a terrain model based on recent soundings throughout the entrance (the 1998 bathymetry is discussed in Chapter 3).

An estimate of maximum likely uncertainty in the calculated cut volumes is 100,000 cu yd/mile (equivalent to about a 2-ft uncertainty in the 500-ft-wide design). In addition, actual volumes that will be required to create the selected alternatives may differ from those calculated here because the bay entrance is continually being remolded. Errors arising from imprecise knowledge of the 1998 bathymetry are probably small compared to changes that could occur prior to actual dredging. The temporal changes do not, however, overshadow the wide range of cut volume requirements among design alternatives. Calculated volumes are rounded to the nearest 100,000 cu yd in Table 2-3 and still reveal major differences between the alternatives. The initial dredging calculations thus represent reasonable criteria for evaluating initial costs.

Certain calculated differences (e.g., between straight and curved alternatives in the North Channel) also indicate the magnitude of changes in dredging requirements that could occur over a few years. Differences among the calculated values also indicate the magnitude of change in dredging requirements depending on whether the new channel is maintained in a fixed location or allowed to shift with the natural channel (natural migration patterns are discussed in Chapter 3). Following the natural migration would be feasible only within prescribed bounds. When the natural channel approaches unsafe conditions, it would be advisable to establish a completely new outlet farther north where nature began erosion of new outlets in 1941. The cost of maintaining such a moving channel depends on how well natural migration cycles can be anticipated, how soon unsafe conditions recur, and how much extra dredging would be required to force a new outlet ahead of nature's schedule. That extra effort might be similar to the increase in cut volumes going from Alternatives 3G to 3F. Historical channel migration patterns are analyzed in Chapter 3.

Channel designs were based on two cross-sectional dimensions. One provides 26-ft depth plus 2-ft over dredging across a 500-ft width. The other provides 38-ft depths over a minimum 1,000-ft width. Alternative 3B provides 500-ft widths along the straight reaches, but a 1,500-ft minimum width through the curved reaches. An informative illustration of 1,000-ft versus 500-ft widths in Figure 2-5 can be seen along the outer reaches of Alternatives 3A versus 3F and the outer reach of Alternatives 4A and 4E. All designs include 1V-on-3H slopes between the base of the channel and the 1998 sediment surface. Table 2-3 gives the volume calculations for alternatives shown in Figure 2-5. Navigability and alteration of hydrodynamics by dredging were considered in placing these design channels. Minimizing initial dredging was a secondary consideration.

The initial dredging requirements for the 28-ft channel through the middle of the entrance (Alternative 4A) could have been reduced by reorienting the design to the shortest path over the bar rather than to the navigationally preferred alignment shown in Figure 2-5. This less desirable southwest alignment would have reduced the dredging by only about 13 percent and thus is not shown in Figure 2-5, or Table 2-3, or considered further in this report.

For the curved North Channel alternatives (3B and 3G), safe passage of barges on a tow requires a minimum width of 1,500 ft on the curved reaches. Because the naturally curved channel exceeded 28-ft depths over a width that was greater than 1,500 ft in 1998, volume changes were also calculated with a design width that ranged between 500 and 2,500 ft as shown in Figure 2-5. The total cut volume for Alternative 3B was only 200,000 cu yd. By this approach,

Alternative 3B required less dredging than any other alternative and gave considerable extra width in the curves.

For safe passage by barge traffic, the design width of Alternative 3G (the curved 38-ft alternative) was also expanded beyond the 1,000- to 1,500-ft minimum for the straight and curved reaches. A 2,500-ft width was adopted along the entire ocean extension of 3G. The resulting cut volume was only slightly larger (8 percent) than the volume obtained for the 1,000-ft-wide straight alternative (3F).

In summary, Table 2-2 describes the design dimensions for each identified alternative. In calculating initial dredging requirements, these widths were implemented except in the case of the two curved alternatives (3G and 3B). A uniform 2,500-ft width was assigned for Alternative 3G, and a variable width (500 to 2,500 ft) was assigned in calculating the smallest of all the cut volumes (Alternative 3B). These widths illustrate how much wider the 28- and 38-ft clearances could be with little additional dredging beyond that needed for the minimum safe width. The resulting small inflation of calculated volumes also better represents the amount of initial dredging that might be incurred when conditions are not so favorable as obtained with the chosen design channel placements on the 1998 bathymetry. Further such analyses could be performed as new alternatives are identified and existing alternatives are defined.

Navigation Channel Alternatives and Disposal Sites

The location and method of disposal are central factors for evaluating the economic feasibility of potential dredged-material disposal sites. The dredged material is expected to consist primarily of sand. Disposal sites were evaluated relative to proximity to environmental permitting and coordination requirements, environmentally sensitive areas, biological resources, and resource agency requirements. Appendix H describes previously and currently permitted disposal sites, potential new rehandling disposal sites for beneficial reuse, cost of disposal, possible environmental concerns, site capacity, and disposal equipment requirements.

The study determined that more than one disposal site is feasible for the various dredging alternatives. A preliminary attempt was made to assign the disposal site alternatives to the navigation channel dredging alternatives. The matching of channel dredging and disposal site alternatives was a logistical and iterative process that accounted for cost of disposal, schedule of construction, site capacity and volume of dredging, and dredging and disposal equipment compatibility. These preliminary dredging site and disposal site combinations are presented in Table 2-4. Figure 2-6 shows approximate location.

The identified disposal sites, as well as the combination of disposal sites and navigation channel alternatives, are preliminary and would be specified during permitting and design. These dredging site and disposal site combinations may be modified upon possible additional numerical modeling and if new information about channel sedimentation and volume of future maintenance dredging becomes available.

**Table 2-4
Dredging Site/Disposal Site Combination Alternatives**

Channel Alternative	Dredging Volume, cu yd	Description	Disposal Site ¹	Estimated Dredging and Disposal Cost ^{2,3} per cu yd
3A	800,000	Dredge primarily on entrance bar, straight out and fixed in position.	A – Beach Nourishment B – Beach Nourishment D – Nearshore Berm E – North Channel Disposal	\$8.70 \$8.70 \$6.60 \$4.30
3B	200,000	Modified S-curve (moderate curve).	A – Beach Nourishment B – Beach Nourishment D – Nearshore Berm E – North Channel Disposal	\$8.70 \$8.70 \$6.60 \$4.30
3H-a, 3H-b	1,600,000	Added after 1999 survey to coincide with the straight path seaward from near SR-105 project that had minimal change since 1998 survey. <u>Two variations</u> include existing SR-105 (3H-a) and SR-105 dike raised to -2 ft (3H-b).	A – Beach Nourishment B – Beach Nourishment D – Nearshore Berm E – North Channel Disposal	\$8.70 \$8.70 \$6.60 \$4.30
4A	2,300,000	Dredge primarily on entrance bar.	F – Goose Point I – Side Casting	\$6.80 \$3.80
4E	12,600,000	Same as 4A, except dredge to total depth of 38 ft and with width 1,000 ft.	F – Goose Point I – Side Casting	\$5.90 \$3.50
¹ Figure 2-6 and Appendix H give locations of disposal sites. ² Each cost estimate is based on disposal of amount shows in second column, although in some cases, it may be advantageous to dispose of different portions of this amount at more than one site in a given year. ³ Cost estimate does not include mobilization and demobilization.				

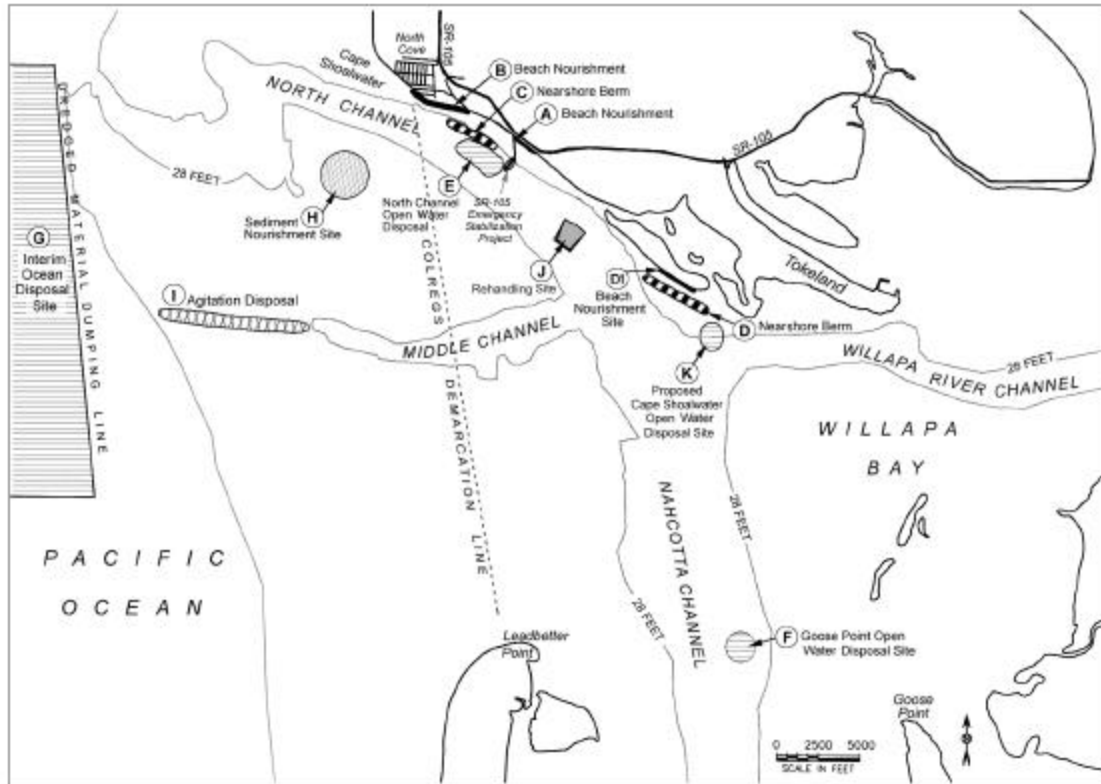


Figure 2-6. Potential dredged-material disposal sites and means of disposal

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